Real Virtuality: emerging technology for virtually recreating reality

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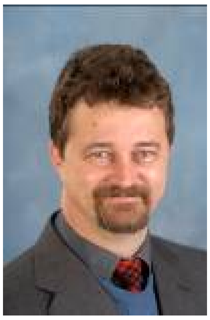

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Introduction

Virtual Reality (VR) attempts to model the real world (present, past, or future) by means of a computer. A user interacts with this virtual environment in order to 'experience' the real world in a safe and controlled manner for any number of applications, including training, education and entertainment. The two key requirements of a VR system are *realism* and *real-time*. Of these, real-time is essential in order to provide an interactive experience to the user. Although it is important to portray the real world accurately, the computational requirements of authentically simulating the physics of the real world have dictated that the quality of realism is always compromised in order to meet the real-time requirements. This article explores the history of VR and considers why, despite some significant contributions to science and technology, this idea has never quite delivered its promise of accurately simulating the real world. To start delivering this promise, we believe that a step change is needed in our approach to VR. In particular the level of realism delivered should no longer be compromised, but rather novel approaches need to be found to deliver the required real-time performance without reducing realism. This is what Real Virtuality offers: *perceptual realism equivalent to the real world at interactive rates*.

One of the earliest VR systems was Morton Heilig's Sensorama of the early 1960s. This device was mechanical and presented the user with a bicycle ride through New York including visuals, audio, the feel of the wind and the smells of the city. Ahead of its time, Heilig was unable to obtain funding for his device and only five short scenarios were ever created. Modern computer-controlled VR systems have come a long way since Heilig's Sensorama and Ivan Sutherland's early attempts at head-mounted displays in 1968. The computational performance of modern hardware and specialised graphics hardware (GPUs) has significantly improved the quality of the interaction and the graphics algorithms. Despite the enormous advances in hardware and software, VR systems continue to reduce realism in order to achieve the desired real-time performance. Most systems today, although compelling, are not physically-based techniques and are thus not capable of accurately simulating the full range of real-world light interactions. Global illumination algorithms are capable of computing such interactions, but for a complex scene even on modern hardware, this may take many seconds or even longer to compute, precluding its use in interactive VR systems.

This is of course only one sense: sight. Humans perceive the world with all five of our major senses: sight, hearing, smell, feel (touch, temperature, humidity etc.) and taste. To provide a 'true real-world experience', virtual environments should have the ability to compute and deliver all five senses in a physically accurate manner. However, even if we fully understood all the physics, such physical accuracy,

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especially as scene complexity continues to grow, is beyond foreseeable computing capabilities for many years to come. Real Virtuality, the focus of this paper, is a step-change from Virtual Reality. Real Virtuality exploits knowledge of how a human processes sensory inputs to achieve multi-sensory virtual environments which are perceptually equivalent to the real scene being represented.

VR in education

VR appears to offer many opportunities for education, for example in enabling students to simulate in a safe and controlled manner scientific experiments which are expensive or hazardous in real life, or to explore other locations or times during geography or history lessons. However, VR has failed to make any significant impact on education. This is primarily due to:

- the cost of VR systems being well beyond the budget of most schools, although recent low-cost desktop VR systems have now put such technology within reach
- the major effort required to create the content for any application. Despite attempts to provide sophisticated Open Source 'authoring tools', for example Ogre3D [http://www.ogre3d.org], the technical requirements and programming skills are still beyond the capabilities of teaching staff, even if they had available the enormous amount of time it takes to create even the simplest scenario.
- the lack of realism, which can often have a negative effect on learning, or even mislead students. For example, a chemical reaction in reality may cause a subtle change in colour, or the emission of the odour when it reaches a critical stage. Failure to adequately represent this in the virtual environment will result in the students missing this key event.

The evolution of VR

Since its inception in the 1960s, VR has taken many forms. Traditional VR systems provided 'immersive' systems either in the form of head-mounted displays or multi-sided rooms with projected walls. Such VR systems proved to be very expensive and difficult to maintain. Although such 'high-end' VR systems are still in use, most modern VR applications run on less 'immersive', but much more affordable desktop and even laptop systems. The affordability of such VR systems, ably supported by the power of modern GPUs, has provided many more people with access to VR. This has inevitably led to a sizeable increase in the number and variety of applications. Of the many variations that VR has taken over the years, three developments are set to have a major influence on the future of VR: augmented reality, massive on-line virtual environments and novel, easy-to-use user interfaces.

Augmented Reality

Whereas VR enables a user to enter an imaginary world, augmented reality adds data, such as labels or even virtual objects, to a view of the real world. A composite view is generated with computer content augmenting the real scene. Augmented reality systems use computer vision techniques, especially object recognition, to accurately align the real and virtual objects. Such techniques usually comprise some form of chequer-board pattern (known as a fiducial) in the real scene which the computer can easily recognise and use to align the virtual object correctly in the 3D space so they appear to be present in the real world. Such optical systems do not operate well in arbitrary light conditions and a line of sight must be maintained between the camera and the fiducial.

Other tracking systems can be:

- mechanical – which are heavy and have restricted range
- inertial – which can suffer 'drift' of the alignment
- GPS and GPS differential – which only work outdoors in wide open spaces and only provide position, not orientation.

One key aspect to ensure the virtual object appears 'naturally' in the scene with the real objects is to light the virtual objects in the same way as the real ones. Such augmentation can enhance the real-world view by providing guidance, for example shop descriptions in a street scene, names of players in a sports match or purchasing furniture by enabling a potential new coffee table to be visualised in your own lounge, as in Figure 2.

Head Mounted Displays (HMDs)

Worn on the head of a user, an HMD provides an immersive visual experience by delivering images to one (monocular) or two (binocular) displays directly in front of a user's eyes. Combined with some form of head tracking, such devices enable a user to 'look around' a virtual environment. These displays have typically comprised LCDs, but more recently OLED technology (which has more contrast and requires less power) is becoming common.

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Figure 1: User wearing an HMD with head tracking; the computer monitor shows what he is seeing

Following a detailed survey in 2008, Sensics Inc. identified that a 'good enough' HMD would have the following attributes:

- A field of view of at least 120×50 degrees.
- At least 1600×1200 resolution, but preferably HD 1080.
- Bright displays with a very fast dynamic response.
- No more than 250 grams (8-10 oz) in weight.
- Easy user interface and cable management.

'The 2008 HMD Survey: Are We There Yet?', Sensics Inc., 2008

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Figure 2: A virtual coffee table placed in a real room

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Figure 3: Augmented reality system for teaching the structure of the brain (image courtesy of Nigel John and Rhys Thomas, University of Bangor)

Medical education is one area which has benefitted significantly from recent advances in augmented reality. Projects such as the Bareta (Bangor Augmented Reality Education Tool for Anatomy) at the University of Bangor are providing high-quality tools for teaching anatomy, reducing the financial, legal and ethical pressures of using cadavers (Thomas and John, 2010).

Massive On-Line Virtual Environments

Implemented via the internet, massive on-line virtual environments are capable of supporting many thousands of participants simultaneously. The users interact in a persistent world, that is, one which is continuously being developed and enhanced. The users can co-operate or compete with each other even if they are geographically far apart in the real world, or just explore the world.

Second Life

Developed by Linden Labs, Second Life is a virtual world in which a user interacts with other users via avatars (virtual humans) in this virtual world. Users can meet, exchange information, and buy and sell virtual objects and property. A modelling tool is provided to enable users to build simple virtual objects. Functionality for these objects can be provided using a scripting language.

While Second Life offers the potential for schools and universities to present classes and schedule student projects, few have yet to take this route owing to concerns about e-security. Conferences and seminars can also be run concurrently in the real world and Second Life, enabling people to listen to the presentations from all over the world. This was the case for the recent 2009 IEEE Conference on Games and Virtual Worlds for Serious Applications held at the Serious Games Institute in Coventry. As well as being able to follow the presentations live, remote viewers could also submit questions to the speakers. It is even possible to make real money by buying and selling virtual objects. Indeed, Ailin Graef became a (real) millionaire through her Second Life avatar named Anshe Chung, who brought virtual properties, developed pleasing architecture on them and then subdivided and resold or rented them for real money.

World of Warcraft

Produced by Blizzard Entertainment, World of Warcraft (WoW) is a ‘massively multiplayer online role-playing game’ (MMORPG). Players join the system by paying a monthly subscription, create an avatar and then set out into the imaginary world to slay monsters and find treasure. As with Second Life, the key to WoW is player interaction. Players from all over the world can join together to solve quests, interact with the environment (including non-player characters) and trade. WoW holds the Guinness World Record for the highest number of subscribers, currently over 11.5 million.

Real time sports events

More recent developments in ‘many-user real-time augmented reality environments’ include allowing viewers to participate in sports events, although without actually being able to interact with the real participants. For example, Real Time Race just

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announced their system, due out in 2010, which should allow players to race ‘live’ against real participants of a Formula 1 event (BBC, 2009).

Novel input devices

The Nintendo Power Glove of the early 1990s attempted to provide a natural interaction with virtual worlds through hand movements. The device was not a commercial success as it did not have a high precision and was difficult to use. The Power Glove did, however, lead to the development of the Nintendo Wii. Launched in 2006, the Wii Console and its controller, the Wii Remote, enable users to interact with the computer in 3D space. Users can therefore use physical gestures to interact including recreating sports-like actions, such as playing tennis and bowling. With over 13 million sales so far, the Wii offers a far more natural interaction with a virtual environment to a wide audience.

In addition to the Wii, there have been many more research developments in input devices, although few have made it into the commercial market. These include gesture-based systems, and motion-capture devices which accurately determine a user’s posture, including eye gaze direction, such as those being developed at SMARTLab [http://smartlab.uel.ac.uk/new2009/], and use them to manipulate the virtual environment. The ACM SIGCHI organisation with its annual conference [http://www.sigchi.org] attracts many thousands of attendees and presents the latest developments in novel user interfaces, while the International Conference on Multimodal Interfaces showcases the latest advances in this area [http://icmi2009.acm.org/].

Real Virtuality: a step change from Virtual Reality

Humans perceive the world with our major senses: visuals, audio, feel, smell and taste. Cross-modal effects, i.e. the interaction of these senses, can have a major influence on how environments are perceived, even to the extent that large amounts of detail perceived by one sense may be ignored when in the presence of other more dominant sensory inputs (Calvert *et al*., 2004). Traditional Virtual Reality systems cannot provide such a full sensory experience because they (a) do not stimulate all the five senses and (b) the stimulation for each sense that they do provide typically gives only a restricted experience. Real Virtuality, on the other hand, is defined as a true high-fidelity multi-sensory virtual environment that evokes the same perceptual response from a viewer as if he/she was actually present in the real scene being depicted (Chalmers *et al*., 2009). Such environments are interactive, based on physics and with information for all five senses delivered in a natural manner.

Recent research has shown that in order to deal with all the complexities of living in the real world, the human brain sorts through all sensory input to couple signals that relate to a common event. This is done concurrently while processing the separate sensory input (Calvert *et al*., 2004).

Three principles were proposed by Stein and Meredith (1993) to explain multi-sensory integration:

- *The spatial rule*: when the contributing uni-sensory stimuli originate from approximately the same location
- *The temporal rule*: when the contributing uni-sensory stimuli originate at approximately the same time; and
- *inverse effect*: when the contributing uni-sensory stimuli are relatively weak when considered one at a time.

This section details how all five major senses may be simulated in a virtual environment and the precision this simulation needs to provide in order to accurately portray a real scene.

Reproducing all senses in virtual environments

Visuals

The natural world presents our visual system with a wide range of colours and intensities, from moonlight to bright sunshine. We are capable of seeing between 8 and 12 million colours in the visible spectrum in the range approximately 400 to 700 nanometers. While most modern computer displays are capable of showing about 16 million colours, they are currently unable to show the full range of lighting levels that may be present in any scene. This is very different from our eyes, which can easily adjust from, for example the bright light outside the window, to the dimmer light inside. High Dynamic Range (HDR) imaging is a set of techniques that allows the capture and display of greater dynamic range of luminances between light and dark areas of a scene than normal digital imaging. This wider dynamic range allows HDR images to represent real-world lighting more accurately. In addition, it is possible to display compressed HDR on displays of lower specification, while retaining much of the quality of the picture (a process known as tone-mapping), as in Figure 4.

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Figure 4: HDR imaging (left) False colour image showing the dynamic range magenta=2,000 lux and light blue=3.8 lux (right) – three images at different exposures and (bottom) tone-mapped HDR image shown on LDR display.

Audio

Simple ambient audio can easily be delivered to a virtual environment through speakers or headphones. Such audio is regularly used in VR applications (see for example Begault 1994). However, to achieve the illusion of authentic 3D audio, the individual nature of the acoustic effect of a person's head and shoulders (their head related transfer function) needs to be taken into account. Furthermore, to increase the level of realism, the direction of any sound source should change as the user moves his/her head. This can be achieved by tracking the position of the user's head in real time. There have been relatively few VR applications which include such spatial rendering of sound. Notable exceptions include Tsingos *et al*. (2004) which provided a real-time 3D audio rendering pipeline for complex virtual scenes containing hundreds of moving sound sources and Murphy *et al*. (2007) that presented an accurate numerical method for simulating sound propagation in a virtual environment.

Feel

The human body has the ability to detect about 20 different 'feel senses', including heat, cold, pain, and pressure or touch. We are particularly sensitive to 'feel' in our hands, lips, face, neck, fingertips and feet. Although there has been substantial research carried out in haptics in VR, modern haptic devices are still a long way from achieving the same feedback capabilities of, for example, the human hand which

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consists of millions specialised tactile sensors all working in parallel (a current haptic device will typically contain less than 10 tactile feedback motors). In addition, haptic devices are still limited by being expensive, large and heavy; they also suffer bandwidth limitation, latency between a human operator and the force feedback, being designed for very specific purposes, and instability if the update rate is much less than 1kHz (Robles-De-La-Torre, 2006; Saddik, 2007).

Smell

Although not as developed as our other senses, smell is a key human sense that is strongly linked to memory (Jacobs, 2007). The presence of a smell can have a major impact on how we perceive an environment. For example, the smell of freshly roasted coffee can enhance our enjoyment of a scene, while the odour of rotting flesh is likely to have a major negative effect on our well-being. Despite the importance of smell to humans, this sense has only rarely been included in virtual environments, although it has been used in real exhibits, such as the Jorvik Viking Museum in York, for many years, where the presence of smell has been shown to actually help visitors to remember information (Aggleton and Waskett, 1999). There was a flurry of smell-related activity in 2005 with a number of new companies arising purporting to sell smell generators for, for example the gaming market, such as Trisenx. There was even an extension to the XML language for smell proposed by the Huelva University in Spain. However, despite all the interest at the time, although many of the websites still exist, the companies do not. A recent example of smell in virtual environments includes the pioneering work of introducing realistic smells, including the smell of burning flesh, for the treatment of American veterans from the Iraq war who are suffering from post- traumatic stress disorder (Pair *et al*., 2006). A less dramatic example is the use of smell to enhance a cooking game (Nakamoto *et al*., 2008).

A major challenge for adding smell to virtual environments is to accurately capture the real-world smell and then produce a synthesised equivalent. This is currently achieved by first sucking the air across an Automated Thermal Desorption (ATD) tube. The smell molecules get trapped inside the tube. These molecules can be identified by first passing them through a gas-liquid-chromatography (GLC) instrument, which separates the complex mixture of odorants (many natural odorant mixtures have between 10-600 individual odorant molecules) into constituent molecules. From the GLC, the molecules pass into a mass-spectrometer, which produces a resultant histogram of the molecules present. Current mass-spectrometer devices are not nearly as precise as a human nose and many important component molecules of a particular smell may be missed. Figure 5 shows the process from capture to delivery.

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Figure 5: Capturing and delivering real-word smells

Taste

There are five primary tastes: salty, sour, bitter, sweet and umami (from the Japanese ‘tasty’), which corresponds roughly to the taste of glutamate (Abdi, 2002). Around 75 per cent of taste is actually due to our sense of smell. Loss of our sense of smell, an early indicator of the onset of dementia, is typically detected by people reporting that their food is no longer as tasty, or through the excessive use of salt to try and enhance taste. Smell and taste combine to form *flavour*, which may also be related to other cross-modal interactions (Verhagen and Engelen, 2006). There have been very few attempts to include taste in virtual environments. The most recent example was by Iwata *et al*. (2003), who demonstrated a food simulated at the SIGGRAPH 2003 Emerging Technologies exhibition. A haptic interface mimicked the taste, sound and feeling of chewing real food. A device in the mouth simulated the force of the type of food, a bone vibration microphone provided the sound of biting, while the chemical simulation of taste was achieved via a micro injector.

Selective delivery

In traditional Virtual Reality systems, graphics quality has always been compromised to enable sufficient computational performance to deliver an interactive experience. In Real Virtuality, we wish to simulate all five senses (not just visuals) in a physically-based manner. Even if we fully understood all the physics, to simulate the interactions of all the senses in a physically accurate manner is likely to be much beyond computing capabilities for many years to come. The key feature of Real Virtuality is that it is not necessary to accurately compute all the physics for all the senses. The human brain is simply not capable of processing all the sensory input our bodies are bombarded with every moment of every day. Rather we *selectively process* these sensory inputs to build up a useful, but not necessarily accurate, perception of our environment. Furthermore, the perceptual experience on one sensory input can have a major impact on how our other senses are perceived. Such cross-modal effects can be considerable, with large amounts of detail of one sense being ignored or, by contrast, enhanced when in the presence of other sensory inputs, or when a user’s attention is focused within a scene, such as the ventriloquism effect (McGurk and MacDonald, 1976), inattentional blindness (Mack and Rock, 1998), and the influence one sense has on the others (Ramic *et al*., 2007). For example, there is a restaurant in the UK, the Fat Duck, which provides an iPod Shuffle that plays the sound of the sea when oysters are ordered, as it has been shown that these taste better when accompanied by the sound of the sea (Blumenthal, 2009).

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Understanding what sensory inputs we do attend to, and which we ignore, allows computational effort to be concentrated on those perceptually important parts of a scene (often less than 10 per cent of the whole scene). These can be computed and delivered in high quality, while the remainder of the scene can be computed and delivered at a much lower quality without the user being aware of this quality difference.

Real Virtuality thus delivers an experience that is perceptually equivalent to the real-world experience, without the need to compute full physical accuracy. The delivery mechanism of Real Virtuality is termed a ‘virtual cocoon’. This is a helmet-like device that contains high-quality visuals, 3D audio headphones, smell and tasting technology, and temperature, humidity and wind simulation devices (Figure 6).

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Figure 6: The virtual cocoon

There are two distinct scenarios for Real Virtuality:

- **Captured:** in this scenario, the real world is delivered in real time to the virtual cocoon. This is achieved through devices which simply capture all of the sensory data and transmit it for delivery to the virtual cocoon.
- **Modelled:** here environments, including the interaction of all the sensory information, have to be accurately modelled.

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Figure 7: Temple of Kalabsha (left) today and (right) as it may have appeared in 30BC

So, for example, in Figure 7, the sights, sounds, smells, temperature of the Temple of Kalabsha near Aswan in Egypt, could be simply captured and delivered to enable a user to experience the temple as it appears now. However, if we want to experience the temple as it may have appeared in 30BC, then a computer model is necessary to simulate accurately each of the senses of the temple in the past (Sundstedt *et al*., 2004).

Levels of realism (LoR)

The level of realism (LoR) required in any virtual environment depends largely on the demands of the application. When recreating the real world it is important to achieve a *one-to-one mapping* of an experience in the virtual environment with the same experience in the real environment (Chalmers and Ferko, 2008). This is particularly important for training situations, where failure to achieve this one-to-one mapping runs the real risk that the user may adopt a different strategy in the virtual training situation than they would do in the real world (Mania *et al*., 2003).

Believable realism

Modelling real environments on a computer often results in the imagery looking pristine (Figure 8, middle), and the sounds too ‘crisp’. The real world is seldom pristine and includes accumulated stains, dust, and scratches from everyday use, and background noises from all manner of objects. The absence of such ‘scruffy enhancements’ can have a significant effect on a viewer’s perception of the realism of that environment (Longhurst *et al*., 2003).

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Figure 8: Believable realism – photograph (left), computer graphics (middle) and graphics with scruffy enhancements (right).

A key challenge in creating realistic virtual environments is accurately modelling avatars. Although attempts are made to create to create believable avatars, most fail owing to the uncanny valley phenomenon in which the avatar is ‘almost human’ but because it is not ‘fully human’ and humans are particularly sensitive to the appearance of other humans, the avatar appears ‘strange’ (Mori, 1970).

Comparing real and virtual scenes

It is one thing to create a computer model of a real scene, it is quite another to validate just how accurate the virtual environment is compared to the real scene being portrayed. A number of objective and subjective ways of comparing real and virtual scenes have been developed over the years to investigate the authenticity of computer imagery (Chalmers *et al*., 2000). For example, Rushmeier *et al*. compared the quality of a photograph with the real scene using perceptually based metrics (1995). More recently (2005) a high dynamic range visual difference predictor (HDR-VDP) has been developed by Mantiuk *et al*. Faraday (1999) suggested there are four parallel processes in human vision: head movement, eye movement, visual perception, and cognitive processes. These often work in conjunction, rather than independently, to influence a person’s perception of a scene. Thus a holistic approach must be taken when comparing real scenes and their synthetic image equivalences. McNamara *et al*. (2000) used judgements of lightness in both the real and virtual scenes. Based on early work by Gilchrist *et al.* (1983), McNamara *et al*. showed that the perceptual visual equivalence of a given real scene and a faithful representation of that scene could be quantified.

Presence is currently a popular metric as a subjective measure of the fidelity of a virtual environment (Slater *et al*., 1994). This is often seen as a measure of technical immersion, with the higher level of technical quality, especially in the areas of picture quality, field of view and level of interaction, providing a higher sense of presence

(Witmer and Singer, 1998). It does not, however, by itself, provide a measure of perceptual equivalence.

Conclusions

In over 40 years, virtual reality has promised much, but delivered relatively little. Although Heilig's Sensorama of 1962 had multiple senses, very few VR systems since then have included more that two senses (visuals and audio, or visuals and haptic), despite the fact that many computer games now regularly include multiple senses including force-feedback through joysticks and steering wheels. In addition, many simple interactions for a human in the real world are still challenging problems in the virtual one, for example walking, although there have been many attempts to solve this including omni-directional treadmills and the Virtusphere.

Realism has always been a challenge for Virtual Reality. The need to maintain an interactive user experience has taken priority, resulting in visuals, and in a few cases other modalities, which are woefully short of what we experience in the real world. Although many applications don't need a high level of realism for the user to successfully complete their task, for those that do, however, some form of selective delivery must be employed to at least achieve *perceptual realism.*

Real Virtuality is a step-change from traditional Virtual Reality by delivering perceptually accurate visuals, audio, smell, feel and taste to the user simultaneously in real time. This allows Real Virtuality to exploit cross-modal effects which are a key feature of how humans perceive the real world and in doing so significantly reduce the amount of computation actually needed for any environment. This, coupled with the processing power of modern computer hardware, including parallel processing, allows Real Virtuality to achieve 'realism in real time', despite the high computational demands of high-fidelity, physically-based rendering.

The possible applications of Real Virtuality are many. For example, in education these could include:

- recreating the past, such as experiencing a full multi-sensory ancient Rome during history or Latin lessons
- experiencing the world by, for example, visiting a café in France while remaining in the classroom in the UK
- fully immersive remote meetings or performances, such as selecting your desired listening position at a concert in the Albert Hall.

In addition Real Virtuality offers many other possibilities for drivers, fire-fighters and pilots amongst others to gain perceptually accurate full multi-sensory experience in simulations of highly dangerous conditions in a safe and controlled environment. Archaeologists can explore the past through testing different hypotheses in a trial-

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and-error process without any actual consequence to a sensitive cultural heritage site and military personnel can obtain compelling training, which could even include real-time experiences such as being on patrol, for example, in Afghanistan.

As with Virtual Reality, the success of Real Virtuality depends on it delivering its promise of ‘experiencing real world modalities in a natural manner in a virtual environment’ and the technology being affordable and accessible to a wide range of users. The key is that Real Virtuality does not compromise on the perceived realism of the virtual environment. This allows Real Virtuality to really represent the real world in a safe and controlled manner, and accurately simulate, for example that subtle change of colour or release of an important odour during the chemistry lesson.

Virtual Reality is not about to ‘disappear’, as a rapid growth in VR applications is likely in the next few years, benefitting from developments such as the Nintendo Wii. Education will continue to look at virtual environments as a way of providing students with enhanced learning experiences at a low cost without the need for expensive (and potentially dangerous) science labs or field trips. Real Virtuality is a new step-change alternative to Virtual Reality. As the technology to deliver all major senses to virtual worlds matures, we should see a steady increase in demand for realism coupled with the need for new sophisticated authoring tools to enable users to create their own Real Virtuality content in a straightforward manner. Only then can Real Virtuality begin to deliver a wide range of true high-fidelity multi-sensory virtual environments that give the same experience to a user as if he/she was actually present, or ‘there’, in the real scene being depicted – ‘there-reality’.

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